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The Application of a Microwave Concentrator/Biofilter Integrated System to Treat Paint Booth Emissions

Todd S. Webster, A. Paul Togna, William J. Guarini, Charles Albritton, Charlie Carlisle, Chang Yul Cha, and Joseph D. Wander

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Typical spray paint booth emissions have been shown to be readily treatable using biofilter treatment systems. However, if constant organic loading is not introduced into a biofilter, an effective microbial population may not be maintained. Typical spray paint booths provide a transient, nonsteady-state organic load. Thus, the addition of a concentrator upstream of a biofilter can eliminate these nonsteady-state loading conditions so that the biofilter's microbial population can thrive.

In cooperation with the Air Force Research Laboratory (AFRL/MLQ) and Tyndall Air Force Base (Panama City, Florida), Envirogen (Lawrenceville, New Jersey) and CHA Corporation (Laramie, Wyoming) have recently begun the operation of a pilot-scale integrated microwave concentrator/biofilter system for the treatment of solvents discharged from spray paint booth operations. In the first phase of the treatment process, a ventilated air stream (3,000 SCFM) containing the solvents methyl ethyl ketone, methyl propyl ketone, and toluene from spray painting operations is passed continuously through a granular activated carbon (GAC) moving-bed adsorber. The solvent-saturated GAC is regenerated via microwave energy in a separate regeneration vessel. The solvent vapors are removed from the regenerator by a small stream of nitrogen purge gas and transferred into storage tanks. On a

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continuous basis, solvent-laden nitrogen from the storage tanks is supplied to an Envirogen biofilter along with approximately 100 SCFM of dilution air. Envirogen's biofilter is an air pollution control system in which contaminated air is passed through a bed of organic filter material containing a natural flora of microorganisms. The contaminants are degraded by the microbes on the filter bed into innocuous products of carbon dioxide and water. Critical findings at the pilot scale, overall system performance, and potential applicability at full scale were discussed at the conference.

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THE APPLICATION OF A MICROWAVE CONCENTRATOR/BIOFILTER INTEGRATED SYSTEM TO TREAT SPRAY PAINT BOOTH EMISSIONS

Todd S. Webster[1], A. Paul Togna[1], William J. Guarini[1], Charles Albritton[1], Charlie Carlisle[2], Chang Yul Cha[2], and Joe Wander[3]

Abstract

Typical spray paint booth emissions have been shown to be readily treatable using biofilter treatment systems. However, if constant organic loading is not introduced to a biofilter, an effective microbial population may not be maintained. Typical spray paint booths provide a transient, unsteady-state organic load. Thus, the addition of a concentrator provided upstream of a biofilter can eliminate these unsteady loading conditions so that the biofilter microbial population can thrive.

In cooperation with the Air Force Research Laboratory (AFRL/MLQ) and Tyndall Air Force Base (Panama City, FL), Envirogen (Lawrenceville, NJ) and CHA Corporation (Laramie, WY) have recently begun the operation of a pilot-scale integrated microwave concentrator/biofilter system for the treatment of solvents discharged from spray paint booth operations. In the first phase of the treatment process, a ventilated air stream (2,000 SCFM) containing the solvents methyl ethyl ketone, 2-pentanone, and toluene from spray painting operations is passed continuously through a granular activated carbon (GAC) moving-bed adsorber. The solvent-saturated GAC is regenerated via microwave energy in a separate regeneration vessel. The solvent vapors are removed from the regenerator by a small stream of nitrogen purge gas and transferred to storage tanks. On a continuous basis, solvent-laden nitrogen from the storage tanks is supplied to an Envirogen biofilter along with dilution air. Envirogen's biofilter is an air pollution control system in which contaminated air is passed through a bed of organic filter material containing a natural flora of microorganisms. The contaminants are degraded by the microbes on the filter bed into innocuous products of carbon dioxide and water. Critical findings at the pilot-scale, overall system performance, and the potential applicability at the full-scale system will be discussed at the conference.

Introduction

The treatment of contaminated air [volatile organic compounds (VOCs) and hazardous air pollutants (HAPs)] has received increased attention in recent years, largely as a consequence of the 1990 Clean Air Act Amendments (CAAA). VOCs affect the nitrogen dioxide (NO_2)

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photolytic cycle, and also contribute to the formation of ground-level ozone and other oxidants, the major components of photochemical smog (Wark and Warner, 1981). The CAAA require a significant reduction in HAPs released from major emission sources. There are 188 HAPs currently listed under Title III of the CAAA targeted for reduction, including the common paint solvents toluene, xylenes, and methyl ethyl ketone (MEK) (Driscoll, 1988).

Available options for VOC and HAP reduction from individual sources include the following (1) process changes; (2) raw material reformulation; and/or (3) point source control measures. Existing point source control options include (1) wet scrubbing; (2) carbon adsorption; (3) thermal oxidation; (4) carbon adsorption; and (5) biological treatment.

Biological air treatment is a relatively recent development in the United States. Traditional vapor scrubbing, thermal incineration, catalytic incineration, and adsorption to activated carbon are typically used to treat contaminated air. However, all these methods are potentially more expensive than biotreatment (Dharmavaram, 1991; Chetty et al., 1992). In addition to economic issues, another drawback of both traditional vapor scrubbing and adsorption to activated carbon is that these methods do not destroy the toxic contaminants, but merely transfer them from one medium (air) to another (liquid or solid). Further processing is necessary to destroy the contaminants. Biotreatment processes are environmentally friendly, and produce only non-hazardous by-products such as additional biomass, water, and low levels of carbon dioxide. No carbon monoxide, nitrogen oxides (NO_x), sulfur oxides (SO_x), or thermal pollution are produced.

Most biological air treatment technologies commercially available are fixed-film systems that rely on growth of a biofilm layer on an organic support such as compost, peat, or wood chips (biofilters). If designed properly, these systems combine the advantages of high biomass concentration with high specific surface area for mass transfer (Devinny et al., 1999).

A key to the success of a biofilter system is that a thriving microbial population is maintained. Numerous point source emissions generate transient, nonsteady-state loads. Therefore, the intermittent operation of these point source emissions may not provide sufficient organic loading to sustain a biofilter reactor. One potential solution to this problem is to provide an adsorber/concentrator system as a preliminary step to provide the biofilter with a constant load of organics. In general, granular activated carbon (GAC) adsorbs solvent vapors and other volatile organic compounds (VOCs) at removal efficiencies of greater than 99 percent. The adsorption capacity of GAC is higher than 10% for solvents used in spray painting operations. The GAC bed removes and stores solvents in air and can be used as a concentrator for the biofilter operations. Because GAC is an excellent microwave energy absorber, rapid and controlled regeneration of saturated carbon is possible to supply a constant stream of air containing a steady concentration of solvents. Such a process is not completely unique. There are other commercial processes that use resin beads and microwave heating to capture and concentrate organic vapors in similar manner. However, the effluent air steam is not fed to a biofilter but is burned

Objectives

This project was a collaborative effort between Envirogen (Lawrenceville, NJ) and CHA Corporation (Laramie, WY), in cooperation with Tyndall Air Force Base. The project was funded through the Small Business Innovative Research (SBIR) Program and sponsored by the Air Force Research Laboratory (AFRL/MLQ). The purpose of this research effort was to treat VOC and HAP emissions generated intermittently from a spray paint booth located at Tyndall AFB (Panama City, FL), as a representative application to a Department of Defense coating operation. The generation of a transient, nonsteady-state load of organics requires that a concentrator/biofilter treatment system be implemented. This experiment will provide insight as to the applicability of such a treatment system to spray paint booth operations. The establishment of essential operating parameters and vital performance results will allow for the eventual scale-up of the system.

Experimental Set-up

Concentrator/Regenerator System

The major components of the concentrator/regenerator system include the adsorber, microwave regenerator, compressor, pneumatic carbon transfer system, system monitoring/control hardware and software, the carbon, and the storage vessels.

A ventilated air stream (2,000 SCFM) containing solvents from spray painting operations is treated continuously by the GAC moving-bed adsorber (Figure 1). This adsorber is a two-stage radial apparatus. In the adsorber, the solvents are removed from the ventilation air by adsorption onto the GAC. The carbon adsorbent serves as a solvent vapor concentrator in this type of process. It removes the spray paint solvent vapors from the large air steam, and concentrates them into a smaller stream that is more economically treated. The concentrated stream produced during regeneration of used GAC usually has a flow that is less than 1% of the flow of the original contaminated air stream. The GAC is periodically fed through the adsorption unit via a feed hopper at the top and travels downward.

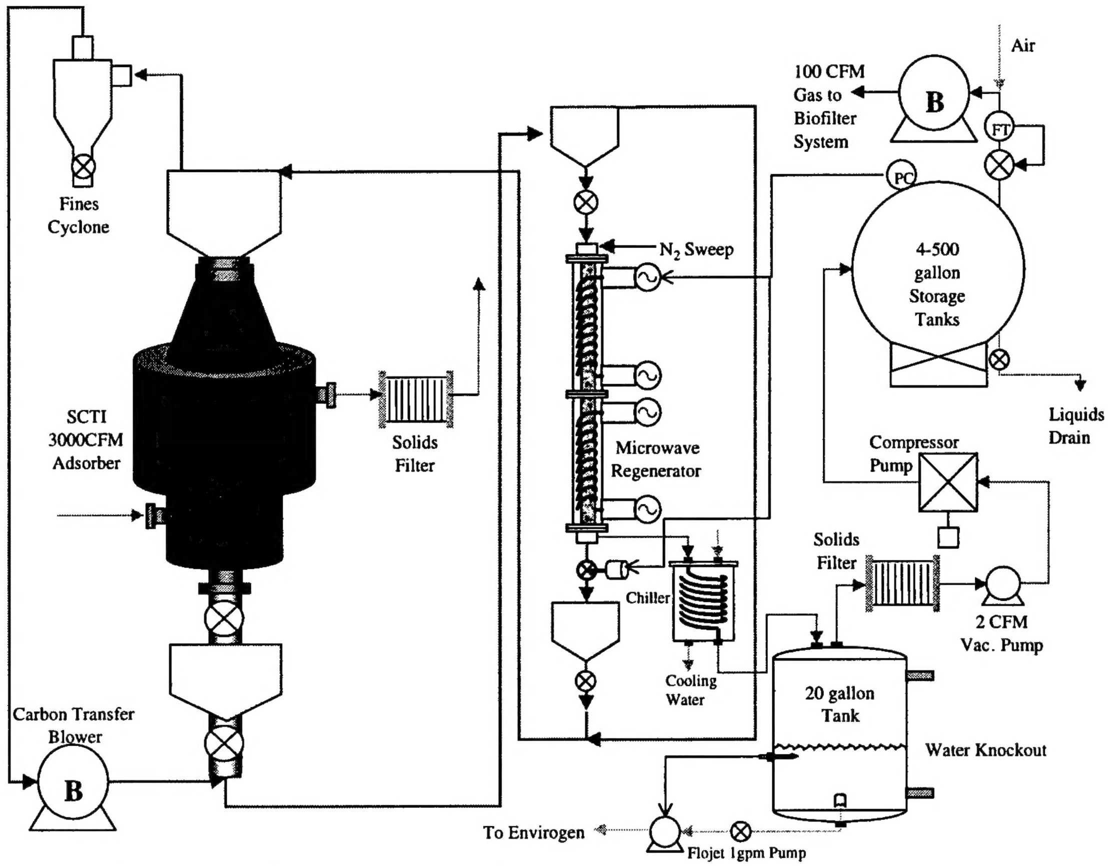

Figure 1. Schematic of the concentrator/regenerator system.

The used GAC exits through a rotating star valve at the base of the adsorber and regenerated GAC is fed into the top of the absorber. The saturated carbon is transported to the top of the microwave GAC regenerator by a pneumatic carbon transfer system. The conveyor air is passed through a cyclone to remove any entrained solid particles during carbon transfer (store >0.5μm carbon fines).

The solvent-loaded GAC is fed into the regenerator by a feed hopper at the top of the regeneration system. Regenerated GAC exits through a rotary valve at the base of the regenerator. The regenerator operates as a moving bed and regenerates the saturated GAC via microwave energy. The basis of the microwave regenerator design is a tee reactor in which a 2.36-inch quartz tube is housed within a 5-inch aluminum reactor body. Microwaves are supplied by home oven magnetrons and transmitted to the saturated carbon flowing within the quartz tube by a launcher, waveguide and finally ¼-inch diameter copper helix that is wrapped around the length of the quartz reactor tube. The copper helix evenly distributes the microwave energy along the length of the quartz reactor tube and promotes consistent solvent desorption. The microwave regenerator has four microwave inputs. Each microwave system includes a magnetron, launcher, directional coupler, adjustable short, power supply, and a short section of 340 waveguide with rectangular flanges. The microwaves cause the solvents to rapidly desorb from the GAC and return to the vapor phase.

The desorbed solvent is removed from the regenerator by nitrogen gas sweep. In this double-tee reactor with central gas porting, the nitrogen sweep gas enters the system in two locations and exits from both ends as well as a 2-inch central gas exit port. The gas porting is designed to remove the desorbed solvent quickly from the reactor so that re-adsorption does not occur.

After the nitrogen/solvent gas mixture exits the microwave regenerator it passes through a chiller/water knockout tank. The knockout tank can drop out 67% of the water removed from the saturated carbon during regeneration. A 20-gallon tank and a float level controller are used for the water knockout. This water is added to the Envirogen water supply for either the humidifier or the biofilter. After the majority of the water has been removed, the gas exits the knockout tank and passes through a solids filter that protects the vacuum pump and compressor.

The small nitrogen stream, 1.0 SCFM, containing a high concentration of solvent is compressed into four 500-gallon storage tanks. These tanks allow for a continuous feed to the biofilter because regeneration is periodic rather than continuous. A small stream of solvent-laden nitrogen is withdrawn from the storage tank and combined with 100 SCFM air to supply solvent vapor to the biofilter. Outside air will be used, but the opportunity exists to recycle part of the treated effluent and enhance the extent of destruction.

The concentration of the gas exiting the storage tanks is monitored continuously with on-site analyzers and the flow to the biofilter is adjusted accordingly. Pressure in the storage tanks is regulated and the biofilter feed rate is controlled by an air-actuated gas flow valve coupled to an I/P actuator controller. The gas flow is monitored by a flow meter.

The control system, hardware, and software were purchased from National Instruments. This system is capable of monitoring and controlling the CHA paint vapor concentrator and Envirogen biofilter with only occasional human attention needed.

Biofilter

Envirogen has installed a P600 series biofilter at Tyndall AFB (Figure 2). The P600 series biofilter contains 600 cubic feet of filter media (proprietary compost blend mix) that treats 100 SCFM at a 6-minute contact time. The entire system is composed of a control panel, blower, humidification chamber, and biofilter vessel that sits atop a 40'x8'x4' trailer.

The contaminated air from the concentrator unit enters the blower at 100 CFM. The air is passed through the bottom of a humidification chamber where the air is saturated with water. The saturated air enters the bottom of the biofilter reactor system through a plenum. The air is passed upward through the media bed where it is treated and released to the atmosphere. Weep hoses are provided at various heights along the filter bed to provide substantial moisture control. Water is drained from the bottom of the reactor. A portion of this water is wasted to a drain while the rest is combined with fresh water and recycled back to the filter bed. This recycling of the wastewater provides nutrient return to the system and minimizes wastewater generation.

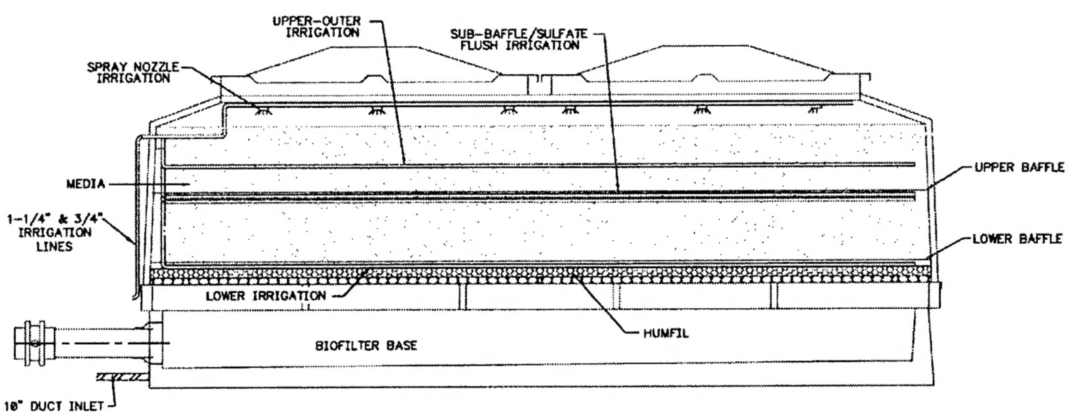

Figure 2. Schematic of the biofilter reactor.

Methods

During the operation of the system, numerous types of air and water analyses are conducted on-site to determine and maintain system performance.

Air Analysis

On-site air analysis of total organic concentrations is performed using one Eagle™ EM-700 (Irvine, CA) and two Thermo Environmental Instruments Model 51 total hydrocarbon analyzers that sample continuously. The analyzers measure air concentrations at the inlet of the adsorber, before the biofilter (after storage tanks), and after the biofilter reactor. The instruments use methane as a calibration gas standard. The data obtained from the analyzers are automatically logged into a data acquisition system. In addition, grab samples of air are also obtained on a periodic basis and are analyzed using Methods EPA TO-12 (total non-methane organics) and EPA TO-14 (aromatics, ketones, etc.).

Water Analysis

Water samples for on -site analysis are periodically collected from the biofilter in order to assess the nutritional requirements of the microbes in the reactor. On-site analysis includes the use of HACH® (Loveland, CO) measuring kits for the analysis of ammonia-nitrogen, nitrate-nitrogen, phosphate-phosphorus, hardness, and pH.

Results and Discussion

Experiments involving the integrated systems (adsorber/regenerator and biofilter) are currently being conducted. After installation and initial operation, it was discovered that the adsorber loading provided by the spray paint booth was extremely low. This inadequate loading occurred because of changes in the paint booth operation that led to more efficient control of VOC emissions during paint application. In order to assess the overall effectiveness of the adsorber/regeneration system, an artificial load was created to simulate the expected paint booth emissions. System malfunctions and upsets delayed this experiment. Hence, the results of the complete mass balance across the adsorber/regeneration system will be discussed at the conference. In addition, problems associated with scaling-up the adorber/regeneration system will be presented.

Since the paint booth loading has been inadequate and system problems have delayed the artificial load experiment to the adsorber/regeneration unit, an artificial load is being supplied directly to the biofilter to maintain the microbial population. This artificial load consists of a majority of MEK, with smaller percentages of 2-pentanone and toluene. Samples are analyzed along the length of the biofilter and are presented in Figure 3. Based on the low flow and long gas residence time, the majority of contaminant removal (87%) occurs in the first 0.5 feet of bed depth. This percent removal equates to an elimination capacity of approximately 6 g m^{-3} hr^{-1}. In order to assess the kinetics of removal along the biofilter depth, experiments are being conducted with increased inlet loads. As breakthrough occurs at the outlet of the biofilter, a portion of the air is being recycled to the inlet of the biofilter to enhance overall system performance. The results of this experiment will be presented at the conference.

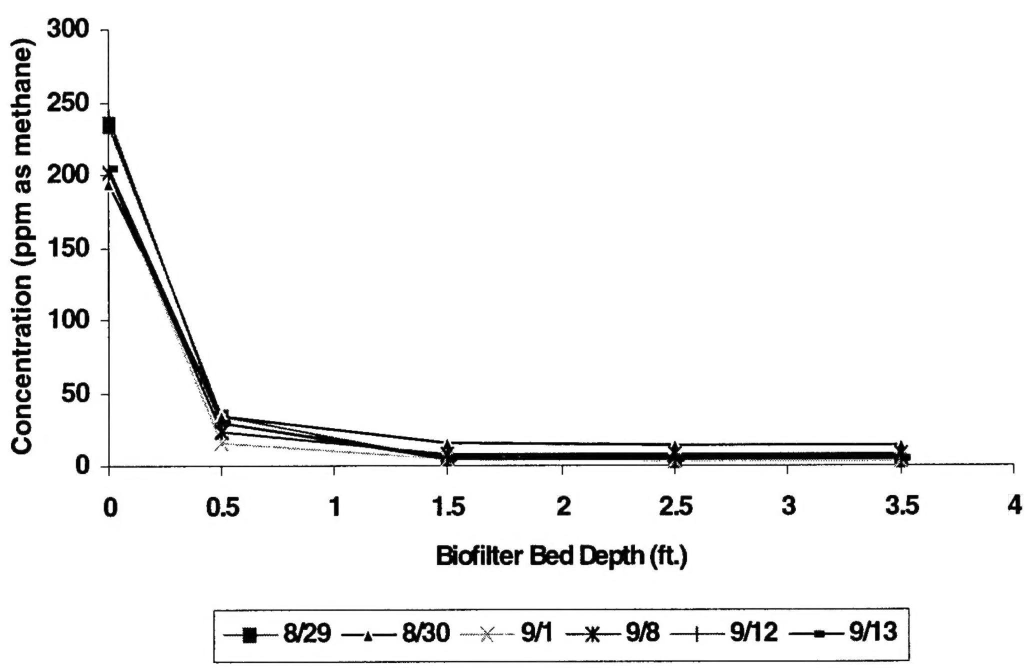

Figure 3. Concentration of contaminant versus biofilter bed depth.

<u>Conclusions</u>

With the cooperation of AFRL/MLQ and the base, Envirogen and CHA Corporation have implemented a concentrator/regenerator//biofilter system at Tyndall AFB for the purpose of treating spray paint booth emissions. Typical spray paint booth emissions have been shown to be readily treatable using biofilter treatment systems. However, if constant organic loading is not introduced to a biofilter, an effective microbial population may not be maintained. Typical spray paint booths provide a transient, nonsteady-state organic load. Thus, the addition of a concentrator provided upstream of a biofilter can eliminate these unsteady loading conditions so that the biofilter microbial population can thrive. Operation of the system is currently being conducted, but a lack of sufficient organic loading from the paint booth has made it difficult to assess the integrated system performance. Instead, an artificial load has been supplied to each system individually. In order to enhance performance across the biofilter at higher loads, recycling of the air is being conducted. These experiments and results will be presented at the conference.

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